

MEMORANDUM

Date: May 27, 2003
To: Kirk Dimmitt
From: Harold Payne and Bruce Brown
Subject: On-Farm Water Conservation Practices

SUMMARY

Tailwater in the Imperial Irrigation District (IID or District) averages about 25 percent of the total water delivered to farms in the District. The annual volume of tailwater is estimated to be 617,000 acre-feet and constitutes 60 percent or more of the total amount of wasted water flowing from IID into the Salton Sea each year. Therefore, the logical question is whether there are low-cost irrigation management practices that can be implemented by IID growers to reduce tailwater losses without adversely impacting crop yields.

Our assignment was to identify and summarize those irrigation management practices that can be rapidly implemented by IID growers to achieve significant reductions in tailwater losses. Nine such management practices were identified which, with minimal instruction, could be utilized with either border-strip or furrow irrigation systems. We described the techniques and identified potential costs and benefits. Our results indicate that under most conditions in IID, each of the nine practices would result in net benefits to the farmer and, at the same time, significantly reduce tailwater. In addition, we identified, in less detail, eight traditional methods that would improve irrigation systems and reduce tailwater in IID through capital investment. These improvements would take a somewhat longer period to implement, with the resulting benefits occurring over a 5- to 25-year period.

All of the nine management practices are low-cost and do not require extensive management training or costly physical modifications of farm fields. There are other practices, more suited for the long-term, which can be used to physically modify the fields to either completely eliminate tailwater runoff, or to limit it to small amounts. These practices range from small-scale laser-grading projects performed within individual field borders, to tailwater recovery systems, to leveling the entire field or installing drip irrigation systems.

All of the practices identified in this memorandum have been utilized by irrigation managers in IID and in other farming areas, and have proven to be effective in either eliminating or greatly reducing tailwater losses and improving irrigation efficiencies.

The following table summarizes the estimated costs to implement short-term management conservation measures in IID. As can be seen, each of these measures requires only a minimal investment that would be readily recovered through reduction in water use, usually within a year. Also, the last column shows that application of these methods affords substantial potential for significant reductions in tailwater over and above the amounts needed to offset the additional costs of implementation. It is our conclusion that a number of these practices are compatible with conditions in IID and can be readily implemented to reduce tailwater losses.

Management Conservation Measures	Costs (\$/acre/year)	Required % Change in Tailwater to Cover Costs	Minimum Expected Tailwater % With Method
Border Strip Irrigation			
Precision Irrigation Cutoff	\$4.00	25% to 20%	5%
Cutback	\$4.00	25% to 20%	5%
Blocked Ends	\$0.35	25% to 24%	5%
Furrow Irrigation			
Cutback	\$6.70	25% to 14%	5%
Furrow Dams	\$3.70	25% to 20%	5%
Soil Surface Conditioning	\$0.51	25% to 24.4%	10%
Bed-Shaping	\$0.84	25% to 24%	10%
Angled Furrows (Curved Furrows)	\$2.56	25% to 24%	0-5%
Alternate Furrow	\$(7.73)	0%	10%

INTRODUCTION

According to Jensen and Walter (2002), the Imperial Irrigation District diverted an average of 3,124,000 acre-feet of water from the Colorado River¹ over the most recent six-year period 1996-2001. Deliveries to farms averaged 2,664,000 acre-feet to irrigate an average of 459,500 acres over this same six-year time period. The average delivery to the farm was 5.80 acre-feet per acre. Also, during the same six-year period, an average of 1,033,000 acre-feet flowed through the District and into the Salton Sea (Jensen and Walter, 2002). This is an average of 2.25 acre-feet per irrigated acre.

Estimates also indicated that the majority of the 2.25 acre-feet per acre that flowed into the Salton Sea consisted of tilewater and tailwater (Jensen and Walter, 2002). Tilewater flows into the drainage system from the extensive on-farm network of tile drains that

¹ Measurements at Pilot Knob.

underlay much of the farm fields within IID. Tailwater is surface water that flows into the drainage system from irrigation events where not all of the water is infiltrated within the field.

Rhoades (2003c) estimates that for a gross IID diversion of 3,100,000 acre-feet, net diversions would be 3,003,000 acre-feet and farm deliveries would be 2,519,000 acre-feet. Tailwater is estimated to be 617,000 acre-feet, or about 25 percent. This is about 60 percent of the total annual flow into the Salton Sea from IID lands. Using the average farmed acres for the period 1989-2001 of 446,000 computed by Gabrielsen (2003), tailwater would average 1.38 AF/acre.

Tailwater is not unique to IID, many other irrigated areas have identified its occurrence as wasteful and have developed a variety of conservation measures to reduce and/or eliminate its occurrence. These conservation measures can be placed into two general groups. One group relies on low-cost management techniques, such as precision timing of irrigation water cutoff and matching water applications to soil intake rates. The other group uses field designs, structures or equipment, such as leveling fields or installing pump-back systems to improve irrigation application efficiency.

Because the list is large, we have selected several conservation measures from Best Management Practices publications of public agencies, from files of irrigation engineers and consultants, and from personal on-farm experience that appear to have applicability in IID.

A. Conservation Measures Involving Improved Irrigation Management Practices

1. Precision irrigation cutoff (Reduced Runoff Practice)
2. Cutback irrigation (Border Strip Irrigation)
3. Blocked ends
4. Cutback irrigation (Furrow Irrigation)
5. Furrow dams
6. Soil surface conditioning
7. Furrow or bed shaping
8. Angled furrows
9. Alternate furrow irrigation

B. Conservation Measures Involving Improved Irrigation Systems

1. Laser Grading
2. Border Extensions
3. Modified Slope
4. Tailwater Recovery Systems
5. Near Level Systems
6. Level Systems
7. Drain-back Systems
8. Trickle Irrigation Systems

The focus of this paper is the first group, improved conservation measures involving irrigation management practices. All of these measures require only a minimal to modest investment and can be implemented almost immediately, with little preparation. Moreover, these conservation measures appear to be appropriate for use in IID, given the conditions that presently exist. Conservation measures in the second group require longer-term installation periods and somewhat larger investments. Nonetheless, some of these systems would be suitable and economically viable for use within IID.

MANAGEMENT CONSERVATION MEASURES

The majority of farms in IID are irrigated with surface-irrigation systems, commonly called flood irrigation. The two most common types of surface irrigation methods being used are border strip irrigation systems and furrow irrigation systems. Various other types of irrigation systems, including drip irrigation, sprinkler irrigation, and level basin irrigation, are utilized on a much smaller scale and, therefore, are not addressed as part of this report.

Border Strip Irrigation

Border strip irrigation can be defined as dividing a large field into graded strips by installation of small dikes or ridges at evenly spaced intervals. Border spacing may vary according to soil type, the slope of the field, the length of the field, crop type, harvest requirements, and the amount of water available to the field. Common border spacings range from 50 to 150 feet. Water is applied at the upper end or head of the strip and flows down the border as a shallow sheet that eventually covers the entire area within the border.

Ideally, flow rates are selected such that the amount of water applied closely matches the amount of water that the soil will absorb during the irrigation period. When the desired amount of water has been delivered to the strip, flow is terminated. Water that has not infiltrated at the time of the cutoff is temporarily stored on the surface of the strip and gradually moves down slope to complete the irrigation. Excess water arriving at the lower end may run into a drainage ditch or may be impounded by closing the border until it eventually infiltrates into the soil or is released to prevent crop damage.

The border strip irrigation method is popular with farmers because:

- It is low-cost and one of the easiest of all flood irrigation systems to construct;
- It has the lowest cost to operate and maintain of all flood irrigation systems;
- Water is applied directly over the soil, which increases the amount of water that can be infiltrated into the soil in a given amount of time;
- High irrigation efficiencies are possible with proper system design, field preparation, and water management;

- It permits the farming of crops in large blocks of land having smooth surfaces, which facilitates movement of equipment across the land for crop cultural operations and crop harvest;
- Irrigation labor costs are low;
- Irrigation management costs are low; and
- It provides superior salinity control since water is applied over the entire area of the border.

Border strip irrigation is most common on forage and grass crops such as alfalfa, sudan grass, bermuda grass, wheat, and barley. Based upon the acreage of these crops in IID, it is estimated that approximately 60 percent of the annual cropped acreage in the District uses border strip irrigation.

The first three conservation management measures listed above (precision irrigation cutoff, cutback irrigation and blocked ends) are appropriate techniques for application to border strip irrigation systems. When used properly, these measures have the potential to reduce or eliminate tailwater runoff from IID fields without affecting agricultural output. The application, costs and benefits are discussed in the following paragraphs.

Precision Irrigation Cutoff

Precision irrigation cutoff involves the timing of the irrigation water cutoff to match the water advance rate and soil infiltration characteristics, such that water advance ceases at about the time the water reaches the end of the border. The time lag between when the water inflow is terminated and when the water stops advancing is called the "recession time." The irrigator is required to monitor the advance and recession time of the irrigation water and adjust the cutoff point of irrigation water to account for changing soil and crop conditions (Exhibit 1).

Crop and soil surface conditions affect the advance rate and influence water infiltration rates which, in turn, affect both the selection of the proper inflow rate to individual borders and the timing of the water cutoff. Field guides written for use by farmers and irrigators have been developed by researchers to estimate the proper distance for irrigation cutoff on borders (Grismer and Tod, 1994). The proper distance for timing the water cutoff can also be determined through trial and error by the irrigator. After several borders have been irrigated, the proper cutoff point in the field can be identified and this technique can be refined such that tailwater losses are minimized.

There is evidence that as early as 1982, precision irrigation cutoff was being used in IID (USBR, 1984). Over a two-year period between 1982 and 1984, a study was conducted by IID and the United States Department of Interior, Bureau of Reclamation (Reclamation or USBR) where tailwater was monitored on almost 15,000 acres implementing the precision cutoff technique. Before the study, IID staff estimated that the tailwater ranged between 20 and 25 percent. During the program, the average measured tailwater spill was 14 percent. In the IID 1984 Water Report (Imperial Irrigation District, 1985), the following was stated relative to the study:

Exhibit 1

Precision Irrigation Cutoff

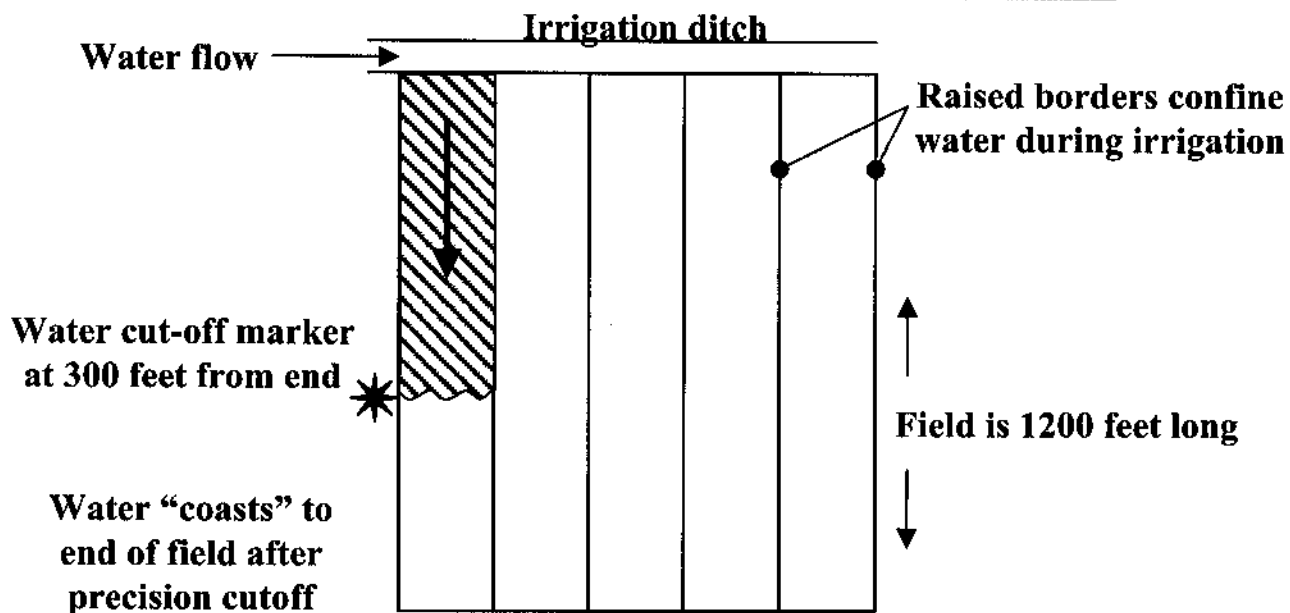
Simple methods to time the cutoff of irrigation water.

Bleach bottle serves as location
marker to signal the cut off water

Alfalfa Crop

Field road

Direction of
water flow



"A small irrigation training program was implemented in 1984. Several farmers and irrigators were trained to observe and record the stream advance and tailwater in border strip irrigation. Adjustments were then made during the irrigation to reduce the amount of tailwater....Previously unit irrigation efficiencies of 70 to 75 percent had been monitored. During 1984 these fields were monitored and unit efficiencies increased to 85 to 95 percent. Although limited in size, this program was very successful (p. 42)."

More recently, two research studies were conducted at the University of California's Desert Research and Extension Center located in the Imperial Valley near Holtville (Bali, et al, 2001; and Grismer and Bali, 2001). Both studies used precision cutoff (referred to as reduced-runoff in the studies) irrigation over the three-year period of 1996-98 on sudan grass and alfalfa, respectively. The Bali (2001) effort resulted in reducing tailwater to less than 2 percent and reducing the annual water application by 28 percent (15 percent due to reduced tailwater) without affecting the alfalfa yield. The Grismer (2001) study reduced tailwater to almost zero with no effect on the sudan yield.

The precision cutoff irrigation technique has little additional cost to the farmer, since the irrigator must already be present at the field, on a regular basis, to care for the water. However, if the irrigator must work harder during the shift, then additional compensation may be required. For example, irrigators are routinely paid \$135 per 24-hour shift. An irrigator may handle two heads (streams) of water and irrigate two separate fields that are 80 acres in size (76 acres net irrigated). It generally takes 36 hours to irrigate the two fields, which costs \$1.33 per acre for each irrigation. If there are 16 irrigations per year, then annual irrigation costs are \$21.28 per acre. Based on one farm where precision cutoff irrigation is practiced in IID, irrigators are paid \$160 per 24-hour shift. It is unknown if the irrigators are paid additional because they have to pay more attention to each irrigation set with this technique than the traditional method or whether the farm pays more for other reasons. If it is assumed that the extra pay is due to additional work required of the irrigator, then the irrigation labor cost increases to \$1.58 per acre and to \$25.28 per acre for the year.

Based on this limited observation, the estimated costs to implement the precision cutoff method would be minimal, around \$4.00 per acre annually (\$25.28 - \$21.28). Assuming that additional irrigation labor is in fact required and compensated at the prevailing rate, the IID average tailwater of 25 percent per acre would only have to be reduced to about 20 percent per acre for those farmers implementing the precision cutoff irrigation method to offset additional labor costs. This reduction would result in about three less inches of water applied to the field by the farmer, which is worth \$4.00 based upon the current IID rate of \$16 per acre-foot for agricultural water.

On the other hand, this irrigation practice has demonstrated dramatic reductions in tailwater without affecting crop yield. For example, if tailwater could be reduced from an average of 25 percent to 14 percent, as indicated in the IID/USBR 1982-84 study, the savings in water of \$14.68 per acre would be more than sufficient to pay for the

additional irrigation labor. This calculation assumes that crop evapotranspiration and leaching requirements are 64.6 inches per season for alfalfa² and that the extra water saved is valued at the current IID agricultural rate of \$16.00 per acre-foot. However, if the saved water is valued at the estimated transfer rate of approximately \$250 per acre-foot, then small reductions in tailwater become very significant.

There are additional benefits from tailwater reduction that include savings in agricultural chemicals, especially those chemicals that are applied in the irrigation water. These benefits are not quantified here due to lack of data; however, conceptually if tailwater is 25 percent, then 25 percent of the water-run fertilizer is wasted out the end of the field. A reduction in tailwater to 14 percent would save 11 percent of the fertilizer previously wasted and further reductions would result in additional savings. For example, if 100 pounds of P_2O_5 fertilizer costing \$.25 per pound is water-run on alfalfa, then 25 percent tailwater carries one-fourth of the fertilizer into the drain during each irrigation event used for fertilization. This costs \$6.25 per acre. Reducing tailwater to 14 percent lowers the cost from \$6.25 per acre to \$3.50 per acre, a savings of \$2.20 per acre. This savings alone would more than cover the increase in irrigation labor of \$1.58 per acre estimated previously.

Implicit within the precision irrigation cutoff management practice is the need for selection of the proper water inflow rate to the borders. Walker (2003) modeled the irrigation conditions for several fields monitored by the NRCE group and evaluated the inflow rates and cutoff times reported in that study (NRCE, 2001). It was shown that with proper selection of inflow rates and cutoff times, that tailwater could be reduced from the levels shown in the NRCE field study. For example, tailwater in Field 1 could be reduced from 28 to 4 percent; in Field 2 from 14 to 4 percent; in Field 6 from 12 to 6 percent, and in Field 7 from 19 to 3 percent. These reductions in tailwater were accomplished using water management changes alone, only adjusting the inflow rates and cutoff times to the proper quantities, with no physical modification to the irrigation system. Since irrigation labor was already in place, any additional costs to implement these changes would be minimal.

The fact that the precision cutoff method is attractive economically under existing conditions in IID may explain why some farmers have already incorporated it into their irrigation practices. The number of farmers utilizing this method in IID is unknown at this time; however, this is one management conservation measure that could be implemented on a much wider scale and would result in significant water conservation through tailwater reduction.

Application of the precision irrigation cutoff method is well-suited to conditions in IID, including the heavy clay cracking soils that occur on approximately 62 percent of district lands. In fact, if precision cutoff were the only conservation measure implemented within IID, a significant reduction in tailwater flowing to the Salton Sea would still be achieved. For example, if the average tailwater percentage could be reduced from the current IID

² Based on 1996-2002 annual average of 59.25 inches for alfalfa as calculated in Allen (2003b) plus a leaching requirement of 0.09 from Rhoades (2003c).

average of 25 percent (1.38 AF/acre) to 15 percent (0.75 AF/acre) on the approximately 275,000 acres that uses border strip irrigation, this would result in an annual reduction of almost 175,000 acre-feet of wasted water. Reducing tailwater to 5 percent (0.225 AF/acre) would mean a reduction of 318,000 acre-feet each year from implementation of just this conservation measure alone.

Cutback Irrigation (Border Strip Irrigation)

In situations where field slopes and/or soil intake rates are such that adequate infiltration has not occurred by the time water reaches the end of the field, additional run time is required to allow water to infiltrate to the required depth. At this point, tailwater is generated while water is held on the field long enough for proper infiltration to occur.

Water lost through tailwater in fields that have these conditions can be minimized by implementing a cutback in water flow at the head of the border strip. The cutback in flow is made before the water has completed its advance to the lower end of the field. By setting the inflow rate high enough to rapidly cover the area bounded by the border with water, and then cutting back the inflow as the water approaches the lower end, the field receives the appropriate water infiltration while keeping the runoff of tailwater to a minimum. The excess water generated at the head of the field from reducing the flow on the border strips that are now fully covered with water can be used to start irrigation on one or more additional border strips at the time of the cutback. This practice was recognized by IID in their Environmental Impact Report/Environmental Impact Statement for the Water Conservation and Transfer Project as being a viable practice available to IID growers to conserve water (IID, 2002).

As with precision irrigation cutoff, cutback irrigation may require slightly more labor and attention from the irrigator during the irrigation set. Nonetheless, cutback irrigation is another conservation measure that requires only changes in management and can be implemented through minor modifications in the irrigator's approach. Benefits are similar to those from precision irrigation cutoff, such as reduced tailwater and decreased losses of agricultural chemicals, with a slight increase in irrigation labor costs. Cutback irrigation can be implemented with little training and only a slight increase in irrigation labor costs, and has the potential to significantly reduce tailwater in IID.

Application of cutback irrigation would be most appropriate for the non-cracking soils in IID that use border-strip irrigation,³ about 85,000 acres. Annual reductions in tailwater would be significant, but on a smaller acreage than the precision cutoff method.

Blocked Ends

The blocked ends conservation method consists of blocking the ends of the borders (raised ridges) to prevent water from leaving the field. Water that collects on the lower end of the field can be retained briefly within the border and then released to an adjacent border, or it can be impounded within the border until complete infiltration occurs. Water

³ Cutback irrigation can also be used with furrow irrigation as explained in a later section.

also may be released to a drainage ditch and removed from the field. Under proper field conditions, this technique can substantially limit tailwater losses. Care must be taken to not scald crops that are sensitive to prolonged periods of ponded water. However, with minor adjustments, the irrigation system can be structured to release water from each border as needed to minimize potential conditions that may lead to scalding. Some crops, such as grasses are more tolerant of standing water (Exhibit 2).

Implementation of the blocked ends conservation measure requires a small amount of additional tractor and operator time to close the ends of the fields. On a per acre basis, it is estimated that the cost of the tractor, equipment and operator would be about \$0.35 (Teegerstrom, 2001). The irrigator would have to be instructed when to open the blocked end to permit the ponded water to flow into the adjacent irrigation set or into a tailwater drainage ditch. This could be accomplished within the irrigator's shift pay and no additional labor costs would be incurred. Where applicable, the blocked ends method only has to reduce a very small amount of tailwater to cover the additional investment required for implementation.

The blocked ends method can be applied to all lands that utilize border-strip irrigation. This method can be used in conjunction with many other conservation measures and is especially compatible with precision cutoff and cutback irrigation. Used alone, a reduction in tailwater of only 0.5 percent would offset the additional costs involved in blocking the ends. Used in conjunction with other methods, blocking the ends will further ensure that tailwater reduction is achieved.

Furrow Irrigation

Another common type of surface irrigation method is a furrow irrigation system. Furrows can be defined as small, evenly spaced channels that convey irrigation water from the top to the bottom of a field. The furrow can be parabolic in shape or have a flat configuration with about a 1:1 side slope. The raised area between the furrows is referred to as the bed, which is where the crops are typically planted. Spacing between furrows is typically about 40 inches, center-to-center, resulting in a furrow width of about 16 inches and a bed width of 24 inches. As water flows down the furrow, it is absorbed into the adjacent beds and infiltrates downward into the bottom of the furrow.

The primary advantage of the bed and furrow system is that the crop is elevated above the water surface to avoid direct contact with the irrigation water. This is a popular system for growing vegetable and row crops such as lettuce, broccoli, cotton, sugar beets, and corn. The furrow system also provides access for mechanical tillage of the soil around the crops to control weeds and to manipulate the soil surface to enhance water intake. In addition, placement of crops on the bed between the furrows facilitates the movement of labor and machinery during cultural operations. However, tailwater losses are typically higher with furrow systems compared to border strips because water flows are confined to a narrow furrow compared to flowing freely over the entire surface of the field.

Exhibit 2

Blocked End Irrigation

Blocking the ends of borders or furrows prevent excess water from spilling.

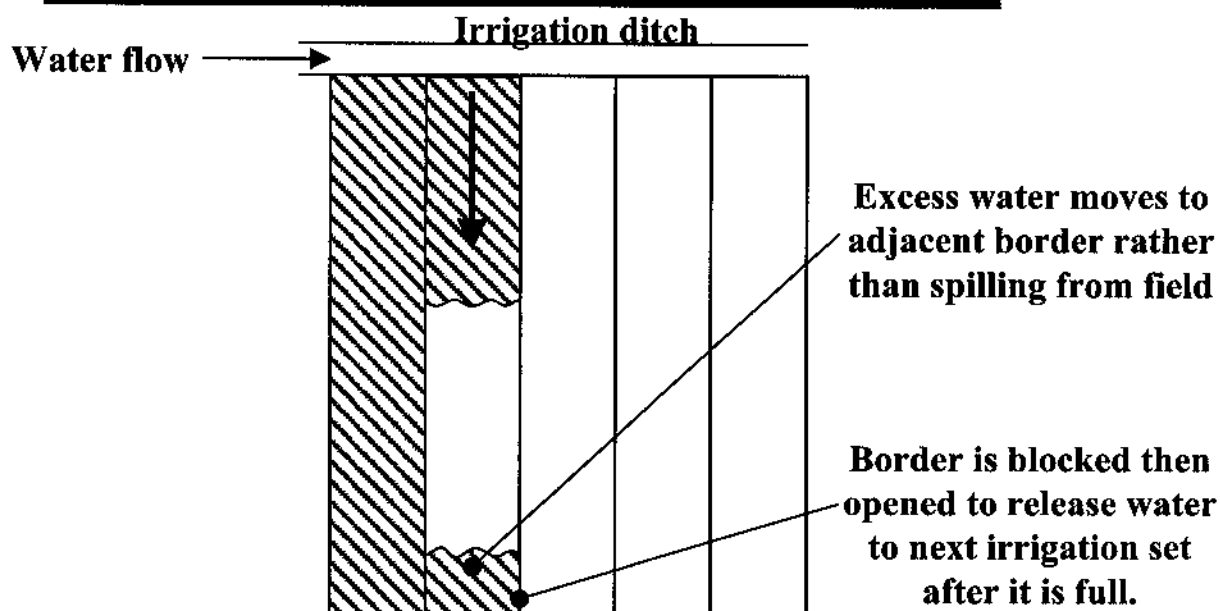
Border to the right is temporarily blocked to retain water. Every other border is blocked. Borders are 75 feet wide.

Irrigation complete

Irrigation just started

Crop is new alfalfa, planted Nov. 2001. January 2002 irrigation.

Lower end is checked to temporarily retain water, released after 3 hours.



Some advantages of the furrow irrigation system are (Jensen, 1983):

- Moderate to high irrigation efficiency is possible with properly prepared land and good water management practices;
- Many different types of crops can be grown in sequence without major changes in the fields;
- Initial capital investment is relatively low since land forming requirements are low and the furrows can be made with common farm implements;
- Soils that form hard surface crusts can be readily irrigated because water moves laterally under the beds. This improves the ability to successfully germinate and establish seeded crops under difficult soil conditions;
- Irrigation water does not directly contact plants and therefore scalding is avoided; and
- A high degree of control of field surface drainage is possible with proper field grades and outlet structures.

Limitations of furrow irrigation systems are:

- Erosion hazards can be high on steep slopes, since irrigation flows concentrate in the furrows;
- Surface runoff occurs, except where the field slopes are gentle or level or where water is impounded until all of it is infiltrated;
- Labor requirements are higher than border or basin systems since irrigation streams must be carefully regulated in the furrows to achieve uniform water distribution; and
- Salts from irrigation water or from the soil may accumulate in the beds around the plants and limit crop yields.

The following paragraphs describe selected conservation measures that have been used on furrow irrigation systems to reduce tailwater runoff. All of these measures can be readily applied to the conditions found in IID.

Cutback Irrigation Method (Furrow Irrigation)

Similar to the cutback irrigation technique described for border strips, water flowing to individual furrows can be adjusted to cover the field as quickly as appropriate, then cut back as water approaches the lower end. This limits the amount of water that leaves the field as tailwater, while still maintaining flow rates sufficient to allow proper infiltration. The extra water generated by the cutback can be used to start new furrows of the next irrigation set (Exhibit 3). This practice offers increased opportunity to limit tailwater losses under furrow irrigation while, at the same time, provides adequate amounts of water to all parts of the field (Bautista, 1993). It has been demonstrated that this technique can reduce tailwater losses by 50 percent or more in furrow systems (Walker, 2003).

Exhibit 3

Cutback Irrigation on Broccoli

Water flow is cut back once water nears the end of the furrows, allowing longer soak time with less water runoff.

**Small wooden stakes used to partially cover buried
PVC furrow pipes to control water flow**



**Small basin at head of field
used to uniformly distribute
water to furrows**

Implementation of the cutback irrigation technique would require additional time by the irrigator to monitor the field and cutback each furrow at the proper time. No field data have been collected with regard to how much additional time would be needed by the irrigator. However, considering that the irrigator would have to return to the set three times instead of two to adjust the flow of water for each furrow, a conservative estimate would be 50 percent. Under the situation where an irrigator is paid \$135 per 24-hour shift, the regular cost per irrigation would be \$1.33 per acre where 152 net acres are irrigated in 36 hours. An additional 50 percent in labor would increase the cost to \$2.00 per acre, an increase of \$0.67 per acre for each irrigation event. The annual per acre cost would depend upon the crop and the number of irrigations required over the course of the year.

On a per irrigation basis, if it is assumed that 4 inches of water are applied per acre and that tailwater is at the district average of 25 percent without cutback irrigation, then the water cost is \$5.33 per acre based on IID's existing agricultural rate of \$16.00 per acre-foot. In this example with 25 percent tailwater, 3.00 inches of water satisfy the evapotranspiration and leaching requirements of the crop and 1.00 inch runs off of the field as tailwater. In order to cover the costs of implementation of \$0.67, tailwater would need to be reduced from 25 percent to 14 percent, then the amount of tailwater is reduced from 1.00 inch per acre to 0.50 inches per acre. This reduces the per acre water cost from \$5.33 to \$4.66, a difference of \$0.67. Without taking into account potential savings from decreased agricultural chemical losses, a reduction in tailwater from 25 percent to 14 percent would offset the additional irrigation labor costs required to implement this conservation measure.

Cutback irrigation could be implemented on any of the furrow irrigation systems in IID (approximately 184,000 acres) with only a small amount of instruction to irrigators (Exhibit 3).

Furrow Dams

The furrow dam conservation method consists of small, triangular pieces of plastic shaped to fit the irrigation furrow to detain the water for more efficient infiltration into adjacent beds. The dam has a small hole in the upper center, acting as a mini spillway, that allows the flow to continue once the water surface has elevated to the level of the hole. Installation of the furrow dam slows the advance rate of water in the furrow and allows more infiltration to occur prior to reaching the end of the field (Exhibit 4).

The additional costs to implement furrow dams would be for the purchase of the dams and installation in the field. The furrow dams are available in at least two types. One type is made durable to last for a number of years and costs \$3.85 per unit. The other type costs \$0.69 per unit and is discarded after one season. Furrow dams are placed in the field for the irrigation set that is running and also for the next irrigation set that will follow. It is assumed that 150 furrows are irrigated in a set; therefore, 300 furrow dams are required. These furrow dams will be used with one head of water to irrigate four 80-

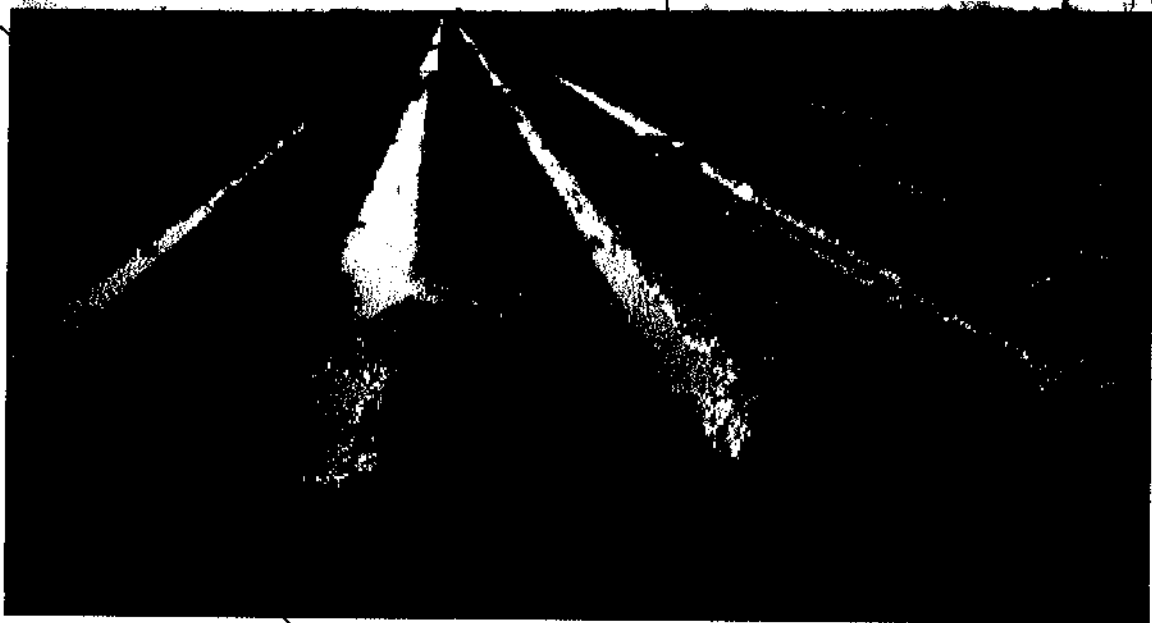
Exhibit 4

Furrow Dams

Plastic dams hold water back on furrows.

Dams have small opening to allow continued water flow after water level in furrow is raised by furrow dam. Soil wets up more quickly with high water levels.

**Broccoli
plants**



**Spreader ditch is dammed every 80 feet
to prevent tailwater runoff**

acre fields (304 net acres). The initial purchase price would be \$3.85 times 300 units for a total capital investment of \$1,155. Assuming a useful life of 5 years and an opportunity cost of 8 percent, the annual cost is \$289.28 or \$0.95 per acre per year.

Although some farmers in IID are currently using this conservation technique, no field data have been collected with regard to additional labor requirements. It is estimated that the extra labor required to place the furrow dams would be 20 percent or less. If 20 percent additional labor is needed, then the cost of irrigation labor would increase from \$1.33 per acre⁴ to \$1.60 per acre for each irrigation, a difference of \$0.27. Assuming that 10 irrigations are made in the season, then the capital cost per irrigation is about \$0.10 (\$0.95/10) per acre and, when added to the additional labor costs, a total cost of \$0.37 per acre for each irrigation is estimated to implement the furrow dam method.

Tailwater would have to be reduced from 25 percent (1.38 AF/acre) to 20 percent (1.10 AF/acre) to break even between traditional irrigation and furrow dams. However, this does not take into account the savings in agricultural chemicals that otherwise are carried off of the field by tailwater. The fact that some farmers are using this technique in IID indicates that this conservation measure is justified under selected circumstances and, because of the preliminary economic indications, certainly merits additional investigation. Furrow dams is a conservation measure that could be implemented quickly and easily, with minimal investment.

Soil Surface Conditioning

Conditioning the soil surface involves conditioning or manipulating the surface of the irrigation furrows prior to an irrigation event in order to slow the advance of irrigation water as it proceeds down the furrows. This operation is normally performed with regular cultivation operations of the crop at a very moderate cost. A small, rotating device is usually attached to the back of a cultivator that leaves small angled dams in the furrow. The cultivator may be modified to roughen up the furrow surface, reshape the furrow configuration, or create small angled dams inside the furrows. These angled dams slow the advance of the water and raise the surface level to increase the rate of infiltration of water from the furrow into the bed and reduce the amount of tailwater from the field (Exhibit 5).

In order to implement the soil surface conditioning technique, it would be necessary to purchase and install the small rotating attachments for the cultivator (or other appropriate toolbar implement). The purchase of 6 attachments would require an initial investment of \$3,390.00 plus about \$20.00 for installation. The annual cost would be \$508.19, assuming a useful life of 10 years and an opportunity cost of 8 percent. If the equipment covers 1,000 acres per year, then the annual cost per acre is \$0.51. A reduction in tailwater from 25 percent to 24.4 percent would justify the additional costs of the soil surface conditioning conservation measure. The soil surface conditioning method could be implemented in IID to reduce tailwater. Additional field documentation should be collected to determine the potential range of expected tailwater reduction.

⁴ \$135 per 24-hour shift, requires 36 hours to irrigate 152 net acres.

Exhibit 5

Soil Surface Conditioning

Diker implement attaches to planters and roughens furrows to retard water flow.



Cotton planters

Propeller-shaped blades form small angled dams to retard water flow during irrigation

Bed shaper forms firm uniform elevated bed for seeding with wide, shallow water furrow to enhance rapid water wetting to seed line

Furrow or Bed Shaping

Bed-shaping uses soil tillage equipment to shape the beds and the furrows in a precise manner to facilitate rapid wetting of the soil around the plants. This practice results in the plants being closer to the water in the furrow, which reduces the time that water must be held in the furrow to wet up the beds where the roots of the plants are located. The net result is a reduction in the amount of water lost as tailwater runoff (Exhibit 6).

Implementation of the bed-shaping conservation measure requires additional machinery and labor costs. The additional machinery includes an implement called a "bed-shaper" that is placed on a tractor. Hourly capital and operating costs for a 4-row bed-shaper used 100 hours per year are \$10.46 per hour, and for a 100 HP tractor used 1,000 hours per year are \$14.18 per hour for a total machinery cost of \$24.64 per hour (Teegerstrom, et al, 2000). The operator wage is assumed to be \$10.00 per hour. The accomplishment rate for this set of machinery has been estimated to be 0.18 hours per acre (Teegerstrom, 2001). Therefore, the cost to complete bed-shaping on one acre is estimated to be \$6.24 ($\24.64×0.18).

Bed-shaping has the potential to decrease tailwater because of the reduced time needed to complete the irrigation event. Assuming that irrigation labor is decreased by 20 percent, this amounts to \$0.54 per irrigation and \$5.40 per acre for a 10-irrigation season. The difference between the additional machinery cost of \$6.24 per acre and the decrease of \$5.40 per acre in irrigation labor is \$0.84 per acre. Accordingly, the bed-shaping method would only have to decrease tailwater from 25 percent (1.38 AF/acre) to 24 percent (1.325 AF/acre) to offset the cost of implementation.

Angled Furrows (Curved Furrows)

The angled furrows water management technique consists of selecting an angle for the furrows that closely matches the natural topographic contours of the field. The result of this layout is that furrows are laid out along a diagonal across the field rather than perpendicular to the head ditch. After collecting field elevation data from a field survey, a precise furrow angle can be chosen that will result in a furrow slope such that the water applied during the irrigation will closely match the intake rate of the soil. This results in the soil being nearly fully wet up by the time the water advances to the end of the field, thereby, eliminating or significantly reducing tailwater runoff. Angled furrows are quite adaptable to fields with steep slopes (Exhibit 7). Most fields in IID have gentle slopes in the range of 0.1 to 0.2 percent (1 to 2 feet of fall per 1,000 feet). Therefore, it would not be necessary to angle the furrows across the entire field to achieve the tailwater reduction. Angling the furrows in the lower portion of the field would have more application in IID as explained in the next paragraphs.

A variation of the angled furrow practice is to lay out the furrows in the traditional north-south or east-west direction, then create a curve in the furrows on the lower quarter of the field, running the furrows against the sidefall of the field (curved furrow method). This

Exhibit 6

Furrow or Bed-Shaping

Wide plant beds and shallow furrows allow water to wet more quickly than deep furrows.

Uniform field grading provides high uniformity of water distribution



Precise shape of plant beds allow planting of seeds adjacent to water furrows to facilitate rapid wetting

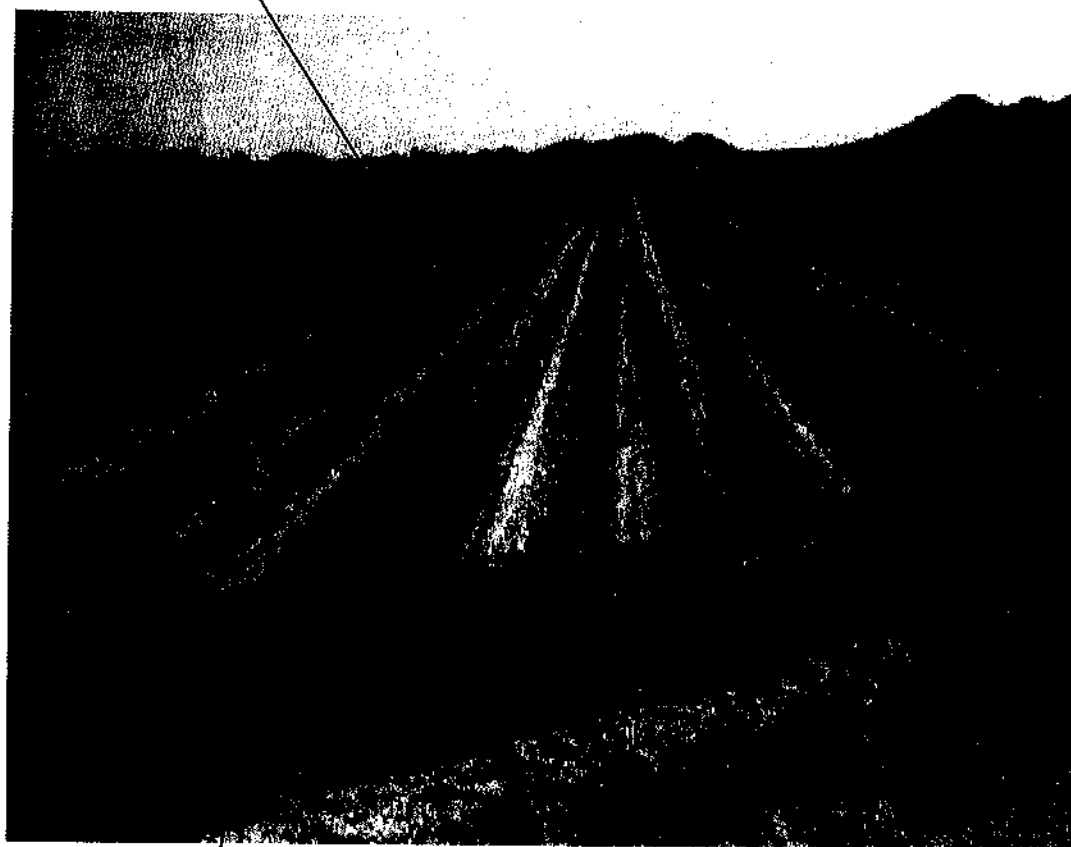
Spreader ditch across lower end connects furrows, uses plastic tarps to control water elevation

Exhibit 7

Angled Furrows*

Precise furrow angle provides flat grade in furrows.

Field is planted to seed but not yet germinated



**Field length
= 660 feet**

**Spreader
ditch is
blocked
every 24
rows**

Lines of planted seeds

**Grade of furrow is dead-flat; row angle is
set to match flat slope when field is
prepared.**

**Water is confined to
alternate furrows (2 rows of
5), while rest of furrows
stay dry**

***Photo depicts dual conservation measures of angled furrows plus
alternate furrow irrigation.**

creates a relatively flat area on the lower end of field that slows the water advance substantially before tailwater runoff occurs, and allows additional time for water to infiltrate before it runs out the lower end of the field. This practice generally is more acceptable to farmers than angling the furrows over the entire field, because the number of total furrows and the number of short angled furrows in the field are reduced in comparison to angled furrows across the entire field (Exhibit 8). Furrows also run parallel to the roads except for the lower portion of the field under this variation. This practice accomplishes the same results as leveling the bottom third of the field without the expense of the required earthwork. However, harvest equipment for some vegetable crops may be hindered by this configuration.

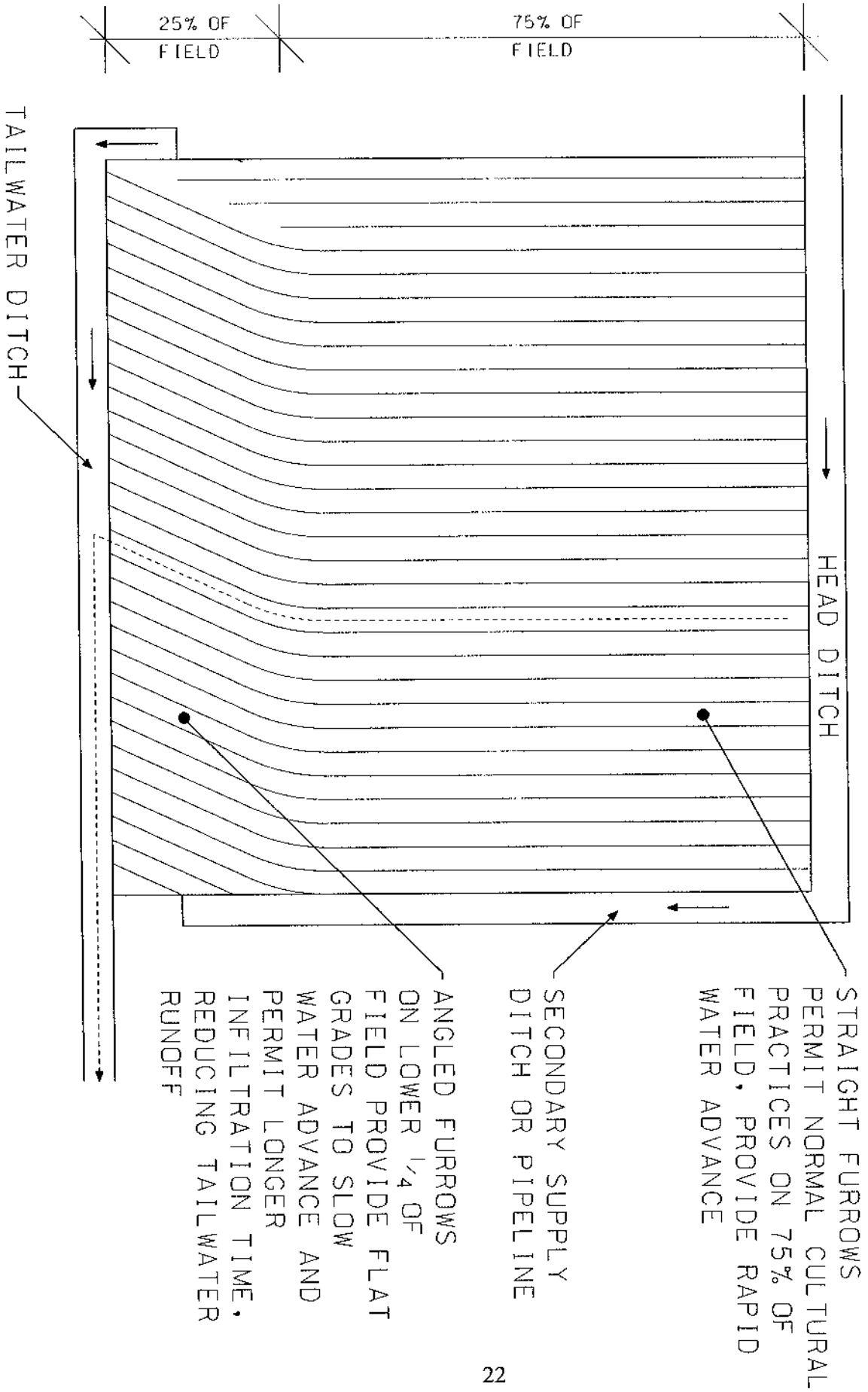
Implementation of curved furrows would require that a flexible plastic pipeline with temporary furrow gates or an earthen ditch be installed along one side of the field to deliver water to the shorter furrows from the point they begin to angle to the lower end of the field. Approximately 1,300 feet of pipeline would be required at a cost of \$0.77 per foot. The total cost would be \$1,001, which equates to an annual cost of \$388.42 based upon a useful life of 3 years and an 8 percent opportunity cost. The annual cost per acre would be \$2.56 (\$388.42/152). Increases in irrigation labor would be negligible because additional field-checks would not be required and operation of the pipeline would only involve controlling the valve at the head of the field. There may be slight increases in the operation of machinery, because of the additional turning requirements; however, these costs are insignificant. Therefore, the estimated total cost of the curved row technique would be about \$2.56 per acre per year.

To put the costs of this conservation measure in perspective, assume that an 80-field has two crops during the year that require 12 irrigations and a total of 6 acre-feet. Tailwater without the curved row technique is 25 percent and the total annual cost of water is \$96.00 per acre. If the curved row technique reduces tailwater to 24 percent, then only 5.84 acre-feet are required, the total annual cost of water is \$93.44 per acre, and the additional costs are offset. Compared to the estimated cost of \$2.56 per acre, a modest reduction in tailwater from 25 percent to 24 percent would offset the cost of the curved row conservation method. In many applications, the curved furrow technique has reduced tailwater to less than 2 percent and sometimes to zero, which affords substantial potential for significant reductions in tailwater.

Alternate Furrow Irrigation

For fields that are irrigated with furrows and beds, it is possible on non-cracking soil types to irrigate alternate furrows (every-other-furrow). This practice is not effective on soils that crack excessively when dry, as the water tends to move beneath the beds to the adjacent furrows that are not being irrigated. However, since about 38 percent of IID soils are not of the cracking type, this practice has application to a significant portion of IID and, in fact, is already in use on some farms located within the District.

Exhibit 8 - CURVED FURROWS



Alternate furrow irrigation is typically done early in the season when the water needs of the plants are small. This practice reduces the total volume of the soil that must be wetted to irrigate the crop, yet provides adequate quantities of irrigation water for the small plants at this stage of development. In some areas of the west, this practice is implemented for the entire season to reduce water use to a minimum, while still meeting the needs of the crop (Exhibit 9).

The benefits of alternate furrow irrigation would be realized through reductions in both water costs and irrigation labor costs. For example, if the first three irrigations use the alternate furrow technique for a crop that requires 10 irrigations in total and it is assumed that irrigation labor is reduced by 30 percent, then the per acre costs decrease from \$2.66 to \$1.86 for each irrigation. Since three irrigation events are involved, the savings in irrigation labor would be \$2.40 per acre ($\0.80×3 irrigations). Also, it is assumed that the first three irrigations use 35 percent less water and that total water usage for 10 irrigations is 40 inches or 4 inches per irrigation. The first three irrigations save about 4 inches of water and reduce total water usage to 36 inches. The difference between the cost of 40 inches of water (\$53.33) and 36 inches (\$48.00) is \$5.33 per acre. The sum of decreased water and labor costs is \$7.73 per acre, which more than offsets any additional costs of irrigating alternate furrows.

Although the conditions in which this conservation method can be implemented may be limited somewhat in IID, it is obvious that this technique has the potential to reduce tailwater when correctly managed. This management practice is even more effective when used in combination with one or more of the other conservation methods described above.

FARM IRRIGATION SYSTEM UPGRADES

The practices described in this section range from minor field modifications to major irrigation system reorganization projects, and all include permanent physical improvements to the farm irrigation system. These improvements are more costly than the management techniques, take longer to develop and implement, and have a payback period spanning several years. Frequently, there are government or irrigation district programs that provide cost-share funding to assist farmers in making these capital improvements on their farms. The result of these system upgrades is both conservation of water, by eliminating water runoff, as well as improved uniformity of irrigation water application, which in many cases can result in long-term improvements in crop yields. System upgrades require a larger investment than management conservation methods and installation occurs over a longer period of time, usually between six months and two years. Payback of the investment usually requires a number of years (usually 5-10). Nevertheless, over this longer time period, system upgrades are cost effective methods to increase water use efficiency and reduce waste.

Exhibit 9

Alternate Furrow Irrigation

Water is confined to every other furrow (2 furrows of 5 = 40% of the total area early-season).



**Cotton plants are still small,
water needs are low.**

**Water is confined to alternate
furrows for 5 of the 10 seasonal
irrigations.**

Laser Grading

Laser grading is a mechanical grading process of soil surfaces to uniform slopes using equipment having a laser-control system to achieve precision field grades. Laser grading results in uniform slopes for border-irrigated fields and eliminates cross-slopes within the borders to provide maximum uniformity for water to spread and advance across the field. Earthwork required with this practice is low, since each border is treated individually. Total water applications, as well as tailwater losses, will be less with this practice than for non-laser graded borders since the water will cover more quickly and a more precise cutoff can be implemented, while still covering the entire border uniformly.

On traditional borders that have not been laser-graded, cross-slope causes more water to flow to the lower side of the border, which is typically 60 to 75 feet in width. This increases the time the water must be run to cover the high side of the border and also increases tailwater water runoff. This is because water must be left on the border until the water on the high side advances to the lower end, while the low side of the border is producing tailwater waiting for the high side to be fully covered with water. The laser grading practice is in use on some Imperial Valley farms.

Border Extensions (Jensen, 1983)

This technique involves the extension of field borders at the end of a field to provide a mini catchment for runoff. This extension area can be planted with a crop that is tolerant of brief periods of impounded water, such as grass crops, while the balance of the field may be planted to a crop that does not tolerate impounded water, such as alfalfa. The border extension should be installed using laser-controlled grading equipment and properly sized to contain the runoff from the upper section of the field. The borders are checked to contain the water and then opened, as needed, to release the water to the next downstream border in the irrigation sequence. This practice can effectively reduce water runoff from agricultural fields, while at the same time providing surface drainage to protect the primary crop from scalding or water logging. It also has the advantage of generating additional revenues from the land dedicated to the border extensions as compared to lands dedicated to tailwater ditches.

Modified Slope

Modified slope involves leveling the final quarter of the field to a very flat grade (0.0 to 0.2 feet total fall) in the direction of irrigation. As water arrives at the end of the field, rather than running into a tailwater ditch, it slows down and gradually spreads across this wide and flat area. The water remains impounded until it infiltrates or is released to the adjacent border, as needed, to protect the crop from scalding. It has been shown by Walker (2003) that for a cost of about \$13 per acre to level the bottom third of the field, this practice can reduce tailwater to 5 percent or less. This practice was also identified in the IID Draft EIR/EIS report as being a viable water conservation practice that could be utilized by IID growers to conserve water for the proposed transfer.

Tailwater Recovery Systems

Tailwater recovery systems can be installed on sloped fields, with or without uniform grades. A pond or impoundment structure is constructed at the end of a field or a series of fields to retain the water that runs off of the field during irrigation. A pump and pipeline system is utilized to recirculate the water back to the top of the field for reapplication until the irrigation is complete.

Near Level Systems

Near level systems can be installed on sloped fields that have been engineered to uniform grades between 0.2 to 0.5 feet of total fall in the direction of irrigation over the entire length of the field. Sideslope may be retained or modified, as appropriate. Field end slope is reduced by moving soil from the high end of the field and depositing it on the lower end of the field so that water does not run off of the field. All irrigation water is retained on the field with this system.

Level Systems

Level border or level furrow systems are constructed so that the field slope is flat or nearly flat, varying from 0.0 to 0.2 feet of total fall in the direction of irrigation over the entire length of the field. Sideslope is also eliminated with this system. Significant land leveling may be required to achieve this condition. High volume water delivery systems are common with level systems and water is introduced to the basins or furrows with gates or ports. Either all irrigation water is retained on the field or a level drain back system is used.

Drainback Systems

Drainback systems are an irrigation technology utilizing headland channel conveyance that is designed and maintained to "drain" excess water applications from one irrigated field to the next down-gradient field. This type of system has a low cost of installation and the ability to drain each basin to the next basin as the irrigation progresses. Construction of concrete field ditches is not required under this system since the headland channel has the dual function of conveyance and distribution. Precise control of water applications is possible with this system and water drainage functions are part of the system to protect against crop damage from standing water.

Trickle Irrigation Systems

Trickle irrigation systems are pressurized surface or subsurface drip irrigation networks that are capable of applying frequent and precise amounts of water to the crop root zone (also referred to as drip irrigation). These systems have proven effective in both reducing water applications and improving crop yields through the use of precision applications of

water and the maintenance of uniform soil moisture with frequent low-volume water applications.

One benefit of the irrigation system upgrades is improved irrigation uniformity, which can translate into improved crop yields on farms where crops yields may be limited by non-uniform irrigation applications. This is an area that needs further research to determine the potential for applying improved irrigation systems and the number of years needed to amortize the investment.

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